EXECUTIVE SUMMARY

Shell Canal Tunnel
Level II Feasibility Study
Contract No. 10-17

Prepared for:
Wyoming Water Development Commission

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October 2011

DEERE & AULT CONSULTANTS, INC.
Water Resources, Civil & Geotechnical Engineering
# Executive Summary

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- Table 2 Engineer’s Opinion of Costs: Tunnel Sleeve Alternative
- Table 3 Engineer’s Opinion of Costs: Open Cut Alternative
- Tunnel Sleeve Conceptual Drawings
- Open Cut Conceptual Drawings

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October 2011
1.0 INTRODUCTION

This report describes the Level II Feasibility Study of the Shell Canal Tunnel completed for the Shell Valley Watershed Improvement District (Project Sponsor) near Shell, Wyoming. The Shell Canal annually carries water through approximately 56 miles of canals and laterals to irrigate about 3,500 acres of crop land. The purpose of the study is to evaluate alternatives for the rehabilitation of the tunnel and to refine conceptual engineering designs and cost estimates for the rehabilitation work.

2.0 BACKGROUND

The Shell Canal Tunnel carries the flows of the Shell Canal through a narrow bedrock ridge in the Northwest Quarter of the Southeast Quarter of Section 3, Township 52 North, Range 92 West in eastern Bighorn County, Wyoming. Upstream and downstream of the tunnel, the canal is in 25-foot (+/-) deep cut sections. The concrete lined tunnel is approximately 562 feet long. The tunnel is a horseshoe section approximately 7.5 feet wide at the invert and 6 feet in height from invert to crown.

The tunnel was reportedly constructed in the early 1900s. Water for the irrigation of approximately 3,500 acres passes through the tunnel annually. Based on information provided at the pre-proposal site visit, the tunnel typically carries flows in the range of 47 to 50 cfs, but could be required to carry peak flows of up to 100 cfs. We understand the canal typically starts running the first week in April and runs until about November 1st of each year.

The Shell Valley Watershed Plan Level I Study completed by Engineering Associates in March of 2010, included a preliminary structural assessment of the Shell Canal Tunnel and seepage losses caused by the tunnel. The assessment found the “structure has far outlived its useful design life.”

The purpose of this new work is to perform a Level II study for the Shell Valley Watershed Improvement District (Project Sponsor) to evaluate alternatives and to refine conceptual engineering designs and cost estimates for the rehabilitation of the Shell Canal Tunnel.

3.0 TUNNEL INSPECTION and ASSESSMENT OF CONDITION

A visual evaluation was conducted on the Shell Canal Tunnel on March 18, 2010. The tunnel was reportedly constructed by blasting through the bedrock with black powder. The tunnel was lined with unreinforced concrete as it was excavated. The tunnel has a horseshoe shaped arch cross-section that is 6 feet tall from the invert to the crown of the arch, it has a 7.5-foot bottom width with a 2.5-foot high vertical straight leg portion. The tunnel concrete was formed with wooden forms. Concrete was placed between the forms and the tunnel excavation. Cold joints are located every 12 feet along the tunnel length, which indicates the forms were 12 feet long. The length of the tunnel is approximately 562 feet and was constructed with concrete transition headwall structures at the inlet and outlet.

The inspection began at the inlet structure (Station 0+00) and continued downstream through the length of the tunnel to the outlet structure (Station 5+62). The description of the tunnel condition references the left and right side of the tunnel facing downstream. For each reach of the tunnel the
section was rated as good, fair, poor, and very poor. This rating reflects the following general
description of the tunnel.

- **Good** - Tunnel has full functionality and only exhibits minor concrete damage or
deterioration
- **Fair** - Tunnel exhibits moderate damage to the concrete and some deterioration
- **Poor** - Tunnel exhibits severe damage to the concrete liner
- **Very Poor** - Tunnel exhibits severe damage to the concrete liner and the liner appears in
danger of failing

The summary of the tunnel section lengths, general description of conditions, and the condition
rating for each section is provided in the following table:

<table>
<thead>
<tr>
<th>Section</th>
<th>General Description of Conditions</th>
<th>Condition Rating</th>
</tr>
</thead>
<tbody>
<tr>
<td>Inlet Structure, Station 0+00</td>
<td>Very cracked and broken, pulling away from tunnel</td>
<td>Very Poor</td>
</tr>
<tr>
<td>Station 0+00 to 1+00</td>
<td>Invert entirely broken up to Station 0+90, regular arch shape, small offsets on cracks</td>
<td>Poor</td>
</tr>
<tr>
<td>Station 1+00 to 2+00</td>
<td>Invert appears sound, regular arch, small offsets on cracks</td>
<td>Good</td>
</tr>
<tr>
<td>Station 2+00 to 3+00</td>
<td>Invert appears sound, regular arch shape, small offsets on cracks, some effervescence</td>
<td>Fair</td>
</tr>
<tr>
<td>Station 3+00 to 4+00</td>
<td>Invert appears sound, arch locally cracked with offsets up to 2&quot;, exposed aggregate, generally more broken</td>
<td>Poor</td>
</tr>
<tr>
<td>Station 4+00 to 5+00</td>
<td>Invert appears to be sound, longitudinal cracks both sides with large offsets up to 4&quot;, arch quite broken</td>
<td>Very Poor</td>
</tr>
<tr>
<td>Station 5+00 to 5+62</td>
<td>Large longitudinal cracks both sides of arch with large offsets, severe cracking on crown and invert, severe transverse crack</td>
<td>Very Poor</td>
</tr>
<tr>
<td>Outlet Structure, Station 5+62</td>
<td>Structure is failing, void behind liner and large area of missing concrete on right side, transition on left cracked and broken</td>
<td>Very Poor</td>
</tr>
</tbody>
</table>

### 4.0 GEOTECHNICAL INVESTIGATIONS

The geotechnical investigation program was developed to answer several fundamental questions for
analyzing, designing, and costing the proposed tunnel rehabilitation alternatives. These questions
are:

1. How thick is the concrete tunnel liner?
2. How strong is the liner concrete?
3. What is behind the concrete liner (i.e., are there voids, timbers, bedrock, sloughed material)?
4. What are the properties of the bedrock in the ridge penetrated by the tunnel? Can these
   materials be excavated by scraper or excavator, or will blasting be required?

The site geotechnical investigations at the tunnel included a general geologic reconnaissance at the
site, as well as investigations of the tunnel liner and the bedrock in the ridge penetrated by the
tunnel. The field work was completed between November 16 and 19, 2010. During the
geotechnical field investigations a detailed survey was also performed by Mr. Paul Reid, PLS.
survey encompasses an area of approximately 16 acres at the site, ranging in width from 300 to 500 feet in the vicinity of the tunnel. The profile and several cross sections of the Shell Canal were also surveyed from the north portal of the tunnel approximately 1,300 feet upstream to the siphon and from the south portal approximately 1,000 feet downstream. The survey resulted in a detailed topographic map of the tunnel site.

4.1 Geologic Reconnaissance

The site is located in the Bighorn Basin in the Central Rocky Mountains Physiographic Province of Wyoming. The regional geology consists of Cretaceous age sedimentary rocks of the Cloverly Formation and Jurassic age sedimentary rocks of the Morrison Formation. These rocks are folded into a series of anticlines and synclines. The tunnel site is situated on the northeastern limb of the Devil’s Kitchen Anticline (Reppe, 1986). The northeastern limb of this anticline dips towards the northeast at approximately five to eight degrees. More recent geologic processes have resulted in the deposition of alluvial, colluvial and residual deposits on the bedrock surface.

Figure 4 of the report is a geologic map of the site. The map shows the tunnel alignment and the location of the geotechnical boring drilled at the site to investigate the bedrock penetrated by the tunnel. Figure 5 of the report is a geologic profile along the tunnel alignment showing the tunnel alignment, the tunnel liner investigation sites and the location of the geotechnical boring.

The Cloverly Formation bedrock at the site generally consists of two distinct rock types: shale and sandstone. The bulk of the Cloverly formation is characterized by massive grey to purple to red shale deposits. The shale unit is the principal unit that impacts the tunnel project. The bedrock structure at the site dips to the north-northeast at approximately 6°.

The primary surficial deposit at the tunnel site is residual soil derived from weathered bedrock. These soils appear to be highly plastic and prone to erosion. A relatively large landslide was observed at the site west of the tunnel (Figure 4 of the report). The landslide is a rotational block slide of Cloverly Formation shale beds that was dislodged from the steep slopes of the hill to the west. The landslide can be clearly seen as the mound just behind and to the left of the drill rig in the photograph below:

![Photograph showing the landslide at the site. Notice the red beds on the hill to the right and the corresponding bed outlined near the center of the landslide mass.](image)
The landslide indicates the relatively weak nature of the bedrock.

The erodible nature of the Cloverly Formation, characterized by badlands-type topography, is also clearly visible at the tunnel site. Piping type erosion is also common in the Cloverly Formation shale. This form of erosion typically occurs along large scale fractures in the rock where precipitation is able to enter the fracture and erode the softer material along the fracture beneath the ground surface. The eroded material is then deposited in topographically low areas that intersect the fracture. This type of erosion can be noticed by the presence of “chimneys” oriented in a line. The chimneys are basically large holes in the ground where material has collapsed into a larger natural pipe underground. Examples of these features measuring about 1-foot in diameter are shown in the photograph below:

![Photograph showing three chimneys connecting the ground surface to an underground natural pipe.](image)

4.2 **Tunnel Liner Investigations**

The tunnel liner investigations consisted of coring and hammer drilling through the tunnel’s concrete liner to investigate the thickness of the concrete and explore for voids behind the liner.

A detailed description of the tunnel liner investigation is provided in the report.

4.3 **Bedrock Ridge Investigations**

The investigations of the bedrock ridge penetrated by the tunnel consisted of drilling of a geotechnical test boring and laboratory analysis of selected soil and bedrock samples collected during the investigations.

A detailed description of the geotechnical drilling program is provided in the report.

4.4 **Laboratory Testing**

Samples of the soils and bedrock were tested in a laboratory for various physical and engineering properties, including: moisture content, density, gradation (including hydrometer and percent passing the #200 sieve), Atterberg Limits, swell consolidation, unconfined compressive strength, soluble sulfate content and resistivity. Laboratory tests were performed on soil and rock samples
obtained from the geotechnical boring, from the core hole at Site B of the tunnel liner investigation and from the outcrop at the downstream invert of the tunnel. The laboratory test results are summarized on Table 1. Laboratory data and gradation plots are included in Appendix C of the report.

The laboratory testing indicates the bedrock surrounding the tunnel is corrosive, has high sulfate contents, and is very plastic and will swell and expand when wetted. The damage documented in the existing tunnel liner arch and walls appears to be the result of the swelling properties of the bedrock documented by the laboratory testing. Similarly, the lab testing indicates the bedrock has index properties that indicate it is subject to frost heave. Combined with the swelling properties this most likely explains the damage to the upstream 90 feet of the tunnel invert.

5.0 ALTERNATIVES ANALYSIS

There are several feasible alternatives that appear possible for rehabilitating the Shell Canal Tunnel. Based on the investigations and the factors listed above, we have focused on three alternatives. These are:

1. **Tunnel Sleeve**: The tunnel would be sleeved with a large diameter heavy duty HDPE pipe. Our analysis indicates a 63-inch diameter thick walled HDPE pipe with a DR 32.5 pressure rating will provide the strength and flow capacity required. The pipe would be blocked up on cradles or installed with rails and encased in cellular concrete. The pipe encased in cellular concrete will be a suitable design to resist the swell pressures and frost heave potential of the surrounding bedrock.

2. **Open Cut Channel**: Replace the tunnel with an open channel cut through the bedrock ridge. This alternative involves complete demolition and removal of the tunnel. The Cloverly Formation shales and sandstones would be excavated to match the exiting Shell Canal flow lines and dimensions.

3. **Conventional Rehabilitation of the Tunnel**: This work would be done using conventional tunneling methods; channel steel rockbolted in-place encased in shotcrete. The concrete tunnel invert would be demolished and replaced with a reinforced concrete invert. This alternative was determined not to be economically feasible during this analysis and was eliminated from consideration.

The Tunnel Sleeve and Open Cut Channel alternatives are discussed in more detail in the following sections.

5.1 **Tunnel Sleeve**

This option probably has the least unknowns and construction risks, and is relatively simple. The tunnel invert would be removed, as appropriate, where it has been bowed upward or needs to be removed in order to maintain the required pipe grade. Cradle blocks would be installed along the length of the tunnel to block the pipe up at the required elevation. The thick walled HDPE pipe would be pushed or pulled into the tunnel by cables from the downstream or upstream end of the tunnel or both. Each 40-foot segment of pipe would be butt welded as the pipe is pulled in. After
the pipe is installed along the entire length of the tunnel, the ends would be temporarily bulkheaded and the annulus space between the pipe and the concrete tunnel liner (as well as possible voids between the existing concrete liner and the bedrock, if required) would be filled with cellular concrete backfill. The grouting would be completed in stages to keep from floating the pipe, or the pipe would be filled with water prior to grouting.

Canal hydraulics will be impacted with the installation of a pipe to sleeve the tunnel. We are proposing installing a 63-inch thick walled HDPE pipe with a DR 32.5 pressure rating. In addition, new inlet and outlet structures will be constructed to replace the existing deteriorated structures. HEC-RAS computer models of existing and proposed conditions were used to evaluate the hydraulic impact of the proposed improvements for flows up to 100 cfs. Survey data provided us with a profile of the canal from the tunnel inlet structure upstream 1,450 feet to an existing inverted siphon. Additional surveying was completed for the inverted siphon and canal upstream of the inverted siphon inlet structure. The results of the model show the capacity of the tunnel lining exceeds 100 cfs, but that there will be a rise in the water surface upstream of the tunnel inlet. This rise is a result of the decreased cross-sectional area of the pipe compared to the existing tunnel cross-section. At 100 cfs the proposed improvements will result in an increased water depth of 1.92 feet at the tunnel inlet structure. The water depth will translate upstream beyond the inverted siphon because there is very little slope on the canal profile upstream of the inlet to the existing inverted siphon. At flow rates of 50 cfs and higher, an increase in the water surface elevation at the downstream end of the inverted siphon will translate to an increase at the upstream end of the inverted siphon. The impacts of the tunnel sleeve option on the inlet to the inverted siphon are shown in the following table:

<table>
<thead>
<tr>
<th>Flow rate (cfs)</th>
<th>Water Surface Elevations (ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Inverted Siphon Inlet</td>
</tr>
<tr>
<td></td>
<td>Existing</td>
</tr>
<tr>
<td>25</td>
<td>4165.17</td>
</tr>
<tr>
<td>50</td>
<td>4165.50</td>
</tr>
<tr>
<td>75</td>
<td>4169.69</td>
</tr>
<tr>
<td>100</td>
<td>4175.33</td>
</tr>
</tbody>
</table>

For flow up to 45 cfs, the water surface at the inverted siphon and the canal upstream of the inverted siphon will show no rise from the tunnel sleeve. At flow rates above 50 cfs, capacity will have to be monitored to make sure the ditch bank is not overtopped. Our model shows that the effect of the tunnel sleeve alternative on the existing conditions of the siphon will not handle flows of 70 cfs and above. Downstream of the tunnel, there will be increased velocity as water discharges from the pipe to the canal due to the decreased roughness of the pipe compared to the existing concrete tunnel lining. We have proposed riprap protection to control the erosion generated by the higher velocity.

The existing concrete inlet and outlet structures would be demolished and replaced with new reinforced concrete structures. The steel reinforcement will be designed to resist damage from differential swelling or frost heave of the foundation bedrock.

**Sheets 1 through 7** of the Tunnel Sleeve Option show conceptual plans for this option.
5.2 Open Cut Channel

This option is mainly an earth and rock excavation project, but includes demolition and removal of the concrete tunnel liner and headwall structures. The soils and Cloverly Formation bedrock overlying the tunnel would be excavated and the tunnel itself removed. This project would involve a benched cut excavation approximately 60 feet deep. The cut slopes would be made at approximately 1.5:1 (horizontal to vertical), with the maximum vertical height between benches equal to 20 feet. A maintenance bench would be provided above the canal for equipment access. The canal cross-section at the base of the cut would be designed to match the existing upstream and downstream cross-sections. The earth and rock from the excavation would need to be disposed on adjacent properties.

Sheets 1 through 6 of the Open Cut Channel Option show conceptual plans for this option.

The open cut option will excavate through the entire bedrock ridge penetrated by the tunnel. The cut will have a maximum width of approximately 250 feet. Excavatability of the bedrock was considered a major concern to be addressed for this alternative. The bedrock penetrated by the exploratory borings found very low to low strength Cloverly Formation bedrock. In general, it appears the upper rock should be excavatable with heavy duty equipment equipped with rippers. However, blasting will probably be required, especially in the deeper bedrock and in more confined excavations.

A second major concern for this alternative is the erodibility of the soils and bedrock, and the potential for slope instability in the high cut slopes. The soils and bedrock are very erodible and maintenance of the slopes and benches should be anticipated. Sediment from the erosion will probably need to be removed from the ditch on a regular basis and may be especially high in the first year or two following excavation.

The proposed side slope angle of 1.5:1 (horizontal to vertical) was selected based on matching the existing cut slopes and natural slopes surrounding the project area. A minor shallow landslide is present in the channel at approximately this same slope angle downstream of the tunnel (see Photograph P41 in Appendix A of the report). This slope was probably undercut with the water flows in the canal. Similar slope failures may occur along the new channel slopes in response to canal flows and there is always some risk for larger scale landslides.

The excavated soils and bedrock, as well as concrete from demolition of the tunnel liner, will need to be permanently disposed on nearby adjacent lands. The materials will need to be placed in a relatively stable fill configuration with graded side slopes. Given the badlands nature of the surrounding areas, vegetating the stockpiled materials is probably not feasible.

5.3 Summary of Analysis

In order to provide a basis for selecting an alternative to carry forward to construction, we prepared a matrix of technical advantages and disadvantages for the three alternatives. This is shown on the following table. Based on this analysis, sleeving the tunnel with heavy duty HDPE appears to be the best alternative with the least risk for both short-term construction issues and long-term operational and maintenance issues. The open channel option appears to provide a secondary
practical alternative that merits costing and conceptual design as well. Based on the high level of uncertainty and anticipated high costs associated with the labor intensive work, conventional tunnel rehabilitation was dropped from further consideration and was not costed.

### Alternatives Analysis

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Advantages</th>
<th>Disadvantages</th>
</tr>
</thead>
</table>
| 1. Sleeve the Tunnel with Heavy Duty HDPE Pipe  | - Fewest unknowns for design and construction  
- Relatively simple construction sequence  
- Short construction schedule  
- All construction within existing BLM right-of-way  
- Long expected service life  
- Low maintenance (same as present)            | - Impacts on canal hydraulic capacity (reduced conveyance cross-section)  
- Requires specialty contractor and equipment  
- Requires construction of new inlet/outlet structures |
| 2. Open Cut Channel                             | - Removes a structure from the canal  
- Maintains or improves existing canal capacity  
- Local earthwork contractor can probably complete work  
- No corrosion risks                             | - Requires additional right-of-way  
- Results in high, erodible cut slopes; risks of slope failure for cut slopes and ditch banks  
- Risks for encountering hard bedrock requiring blasting for excavation  
- Removes access to the other side of the canal at this location  
- Will require increased annual maintenance of ditch slopes and benches  
- Need to dispose demo tunnel concrete and permanently stockpile soils and bedrock on a nearby site |

### 6.0 CONCEPTUAL DESIGNS and COST ESTIMATES

The two alternatives carried into conceptual design and costing are the tunnel sleeve and the open cut options. The conceptual design plan sets for each alternative are attached. This section will outline the conceptual design and costs of the pertinent construction items, contingencies, permitting, engineering, observation and quality control associated with each alternative. A life cycle cost analysis including costs associated with operation, maintenance, replacement, and annual permit fees was also completed for each alternative.

#### 6.1 Tunnel Sleeve

The results of the alternatives analysis indicate that sleeving the tunnel is the best rehabilitation option for the Shell Canal Tunnel in terms of service life, constructability, risk of failure and long term maintenance. Construction of the tunnel sleeve will occur after the irrigation season when the canal is out of service. A summary of the engineer’s opinion of costs is presented in Table 2. The conceptual design plans are attached.

#### 6.2 Open Cut Channel

The results of the alternatives analysis identified the open cut channel alternative as a practical and effective option for rehabilitating the Shell Canal Tunnel. This alternative appears to have more
inherent risk associated primarily with slope instability and long term maintenance. However, channel hydraulics will improve, and it removes a structure from the canal. Like the tunnel sleeve alternative, construction of the open cut will also have to be performed after the irrigation season when the canal is out of service. A summary of the engineer’s opinion of costs is presented in Table 3. The conceptual design plans are attached.

7.0 **PROJECT FINANCING**

It is estimated that the project costs will be $1,120,000 for the tunnel sleeve option and $1,159,000 for the open cut option. The chosen alternative will be financed with a mix of a grant and a loan to the Sponsor. Based on WWDC programs operating criteria, the grant percentage was assumed to be 67 percent and the loan percentage was assumed to be 33 percent. A loan interest rate of 4 percent was assumed. The loan periods examined were 20, 30, 40, and 50 years. The table below presents the different loan options:

### Tunnel Sleeve Option:

<table>
<thead>
<tr>
<th>Loan Period (Years)</th>
<th>Total Project Cost</th>
<th>Grant Amount</th>
<th>Loan Amount</th>
<th>Total Annual Loan Payment</th>
<th>Average Annual Cost per Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>$1,120,000</td>
<td>$750,400</td>
<td>$369,600</td>
<td>$26,876</td>
<td>$7.68</td>
</tr>
<tr>
<td>30</td>
<td>$1,120,000</td>
<td>$750,400</td>
<td>$369,600</td>
<td>$21,173</td>
<td>$6.05</td>
</tr>
<tr>
<td>40</td>
<td>$1,120,000</td>
<td>$750,400</td>
<td>$369,600</td>
<td>$18,535</td>
<td>$5.30</td>
</tr>
<tr>
<td>50</td>
<td>$1,120,000</td>
<td>$750,400</td>
<td>$369,600</td>
<td>$17,106</td>
<td>$4.89</td>
</tr>
</tbody>
</table>

### Open Cut Option:

<table>
<thead>
<tr>
<th>Loan Period (Years)</th>
<th>Total Project Cost</th>
<th>Grant Amount</th>
<th>Loan Amount</th>
<th>Annual Loan Payment</th>
<th>Annual O&amp;M</th>
<th>Total Annual Expenditures</th>
<th>Average Annual Cost per Acre</th>
</tr>
</thead>
<tbody>
<tr>
<td>20</td>
<td>$1,159,000</td>
<td>$776,530</td>
<td>$382,470</td>
<td>$27,811</td>
<td>$3,000</td>
<td>$30,811</td>
<td>$8.80</td>
</tr>
<tr>
<td>30</td>
<td>$1,159,000</td>
<td>$776,530</td>
<td>$382,470</td>
<td>$21,911</td>
<td>$3,000</td>
<td>$24,911</td>
<td>$7.12</td>
</tr>
<tr>
<td>40</td>
<td>$1,159,000</td>
<td>$776,530</td>
<td>$382,470</td>
<td>$19,296</td>
<td>$3,000</td>
<td>$22,296</td>
<td>$6.37</td>
</tr>
<tr>
<td>50</td>
<td>$1,159,000</td>
<td>$776,530</td>
<td>$382,470</td>
<td>$17,106</td>
<td>$3,000</td>
<td>$20,701</td>
<td>$5.91</td>
</tr>
</tbody>
</table>

The average annual cost of the project to the Sponsor is estimated to be between four and seven percent of the current net revenue of the irrigated crop production on the subject 3,500 acres. This indicates that the cost of the project is within the Sponsor’s ability to pay.

8.0 **CONCLUSIONS and RECOMMENDATIONS**

The Shell Canal Tunnel Level II Feasibility Study was performed to identify potential tunnel rehabilitation alternatives. Deere & Ault Consultants has worked closely with the Project Sponsor and the Project Manager during the investigation. Historical information and documents were reviewed to understand the construction and operational background of the tunnel. Access to the tunnel was identified in terms of property ownership and easements.
On March 18, 2010 a thorough inspection of the tunnel was performed. The inspection identified areas of the tunnel that were in poor condition and warranted rehabilitation and/or replacement. In November, 2010 several geotechnical investigations were performed at the tunnel site. These investigations consisted of performing geologic reconnaissance of the site; drilling a geotechnical boring through the bedrock at the site; drilling several core and hammer holes in the existing tunnel liner; and testing samples of soil, rock and concrete for physical and engineering properties in a laboratory.

Using the data collected from the geotechnical investigations, an alternatives analysis was performed. The results of the analysis identified two practical and constructible tunnel rehabilitation alternatives: a tunnel sleeve and an open cut channel. These two rehabilitation alternatives were carried forward into conceptual design and cost estimates. The engineer’s opinion of costs show that construction of the tunnel sleeve will be approximately $1,120,000 while the open cut channel will be approximately $1,159,000.

Permits, easements and clearances needed to build each rehabilitation alternative were identified. Construction of the tunnel sleeve can be done within the existing easement as it is understood. However, to build the open cut option, a new right-of-way easement may need to be obtained, which will include an annual fee be paid to BLM.

Finally, an economic analysis was performed to show how each project would be financed. The results of this analysis show that the average annual cost of this project will be between four and seven percent of the current net revenue of the irrigated crop production. This indicates that the cost of the project is within the Sponsor’s ability to pay.

Based on the conclusions of the Shell Canal Tunnel Level II Feasibility Study, we recommend that the tunnel sleeve rehabilitation alternative be carried into final design for the following reasons. First, the cost estimates for each of the alternatives are similar, but the tunnel sleeve appears to cost about $39,000 less. Second, the tunnel sleeve option presents the fewest risks and uncertainties associated with design, construction, operation and maintenance. Conversely, the open cut option presents a risk of slope instability and will require additional maintenance because of erosion and sedimentation beyond what is currently needed at the tunnel. The increased maintenance will primarily include cleaning sediment from the channel and from the maintenance and access road benches. Further, the potential risk of a large landslide blocking the open cut channel will result in replacing (re-excavating) at least part of the open cut. Finally, the life of the tunnel sleeve will likely equal or surpass the 100-year service life of the existing tunnel liner.
## Table 1 - Laboratory Test Results

**Shell Canal Tunnel**

<table>
<thead>
<tr>
<th>Rock Boring</th>
<th><strong>Hole</strong></th>
<th>Depth (feet) or Tunnel Station (feet)</th>
<th>Sample Collected</th>
<th>Field Classification</th>
<th>Natural Moisture Content (%)</th>
<th>Natural Dry Density (pcf)</th>
<th>Gradation</th>
<th>Hydrometer</th>
<th>Percent Passing No. 200 Sieve (L.L. &amp; Plasticity Index (%)</th>
<th>Atterberg Limits</th>
<th>Swell/Settlement Consolidation @ 1.0 KSF (%) (-Value = Consolidation)</th>
<th>Unconfined Compressive Strength (psi)</th>
<th>Soluble Sulfates Content (%)</th>
<th>Resistivity (ohm cm)</th>
<th>Unified Soil Classification Symbol</th>
</tr>
</thead>
<tbody>
<tr>
<td>B-1</td>
<td>5.0-6.0</td>
<td>Zip Residual Soil</td>
<td>1.05</td>
<td>79 **</td>
<td>CH</td>
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<td></td>
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<td>1.05</td>
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</tr>
<tr>
<td>B-1</td>
<td>6.5</td>
<td>Cal Residual Soil</td>
<td>22.0</td>
<td>95</td>
<td>91</td>
<td>66</td>
<td>3</td>
<td></td>
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<tr>
<td>B-1</td>
<td>20.8</td>
<td>Cal Shale</td>
<td>11.1</td>
<td>37</td>
<td>50</td>
<td>87</td>
<td>12</td>
<td>83</td>
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<tr>
<td>B-1 Run 4</td>
<td>23.7-24.3 HQ Core</td>
<td>15.0</td>
<td>114.2</td>
<td>95</td>
<td>91</td>
<td>66</td>
<td>3</td>
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</tr>
<tr>
<td>B-1 Run 5</td>
<td>30.2-30.7 HQ Core</td>
<td>13.6</td>
<td>109.6</td>
<td>93</td>
<td>84</td>
<td>59</td>
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<tr>
<td>B-1 Run 6</td>
<td>30.8-31.8 HQ Core</td>
<td>11.1</td>
<td>106.1</td>
<td>86</td>
<td>58</td>
<td>32</td>
<td>12</td>
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<tr>
<td>B-1 Run 7</td>
<td>37.0-38.0 HQ Core</td>
<td>11.7</td>
<td>125.6</td>
<td>98</td>
<td>62</td>
<td>41</td>
<td>10</td>
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<tr>
<td>B-1 Run 9</td>
<td>40.5-41.4 HQ Core</td>
<td>12.4</td>
<td>123.5</td>
<td>99</td>
<td>60</td>
<td>36</td>
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<tr>
<td>B-1 Run 10</td>
<td>44.1-45.0 HQ Core</td>
<td>9.3</td>
<td>131.1</td>
<td>99</td>
<td>54</td>
<td>34</td>
<td>8</td>
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</tr>
</tbody>
</table>

**Swell/Settlement**

- **Consolidation**: Percentage of consolidation at 1.0 ksf
- **Swell Potential**: Low = 1% to Very High = 12%

**Unconfined Compressive Strength**

- Bedrock is 190 to 3,050 psi - Very low strength bedrock
- Concrete is 3,350 to 6,010 psi - Normal strength to high strength concrete

Silt & Clay Materials (71 to 99%)

- Plasticity Index - Indication of expansive nature of bedrock, 34 to 155% (CH) is very expansive.
- Swell Potential is Low = 1% to Very High = 12%
- Unconfined Compressive Strength

- Bedrock is 190 to 3,050 psi - Very low strength bedrock
- Concrete is 3,350 to 6,010 psi - Normal strength to high strength concrete

- Soluble Sulfate Content of 0.17 to 1.05% indicates moderate to severe conditions for concrete. Specify Type II concrete and a water/cement ratio (by weight) of 0.45. Specify high strength concrete 4,250 psi (typ.).

- Resistivity of 79 to 236 ohm cm indicates the soils and bedrock are extremely corrosive for buried metal structures or metals in contact with soils or bedrock.
### TABLE 2 - TUNNEL SLEEVE

#### SHELL CANAL TUNNEL

**ENGINEER’S OPINION OF PROBABLE CONSTRUCTION COSTS**

*September 6, 2011*

<table>
<thead>
<tr>
<th>Construction Item</th>
<th>Quantity</th>
<th>Unit</th>
<th>Cost</th>
<th>Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Mobilization, Bonding, Insurance @ 10%</td>
<td>1</td>
<td>LS</td>
<td>$72,500</td>
<td>$72,500</td>
</tr>
<tr>
<td>2 Site Access</td>
<td>1</td>
<td>LS</td>
<td>$9,000</td>
<td>$9,000</td>
</tr>
<tr>
<td>3 Demolition</td>
<td>1</td>
<td>LS</td>
<td>$15,000</td>
<td>$15,000</td>
</tr>
<tr>
<td>4 Earthwork</td>
<td>1</td>
<td>LS</td>
<td>$10,000</td>
<td>$10,000</td>
</tr>
<tr>
<td>5 Pipe Installation (63&quot; Dia. HDPE DR 32.5)</td>
<td>565</td>
<td>LF</td>
<td>$850</td>
<td>$480,250</td>
</tr>
<tr>
<td>6 Cellular Concrete</td>
<td>500</td>
<td>CY</td>
<td>$250</td>
<td>$125,000</td>
</tr>
<tr>
<td>7 Concrete Inlet Structure</td>
<td>1</td>
<td>LS</td>
<td>$30,000</td>
<td>$30,000</td>
</tr>
<tr>
<td>8 Grouted Ripap Inlet</td>
<td>90</td>
<td>CY</td>
<td>$150</td>
<td>$13,500</td>
</tr>
<tr>
<td>9 Concrete Outlet Structure</td>
<td>1</td>
<td>LS</td>
<td>$30,000</td>
<td>$30,000</td>
</tr>
<tr>
<td>10 Grouted Ripap Outlet</td>
<td>60</td>
<td>CY</td>
<td>$150</td>
<td>$9,000</td>
</tr>
<tr>
<td>11 Erosion Control/ Storm Water Management</td>
<td>1</td>
<td>LS</td>
<td>$3,000</td>
<td>$3,000</td>
</tr>
</tbody>
</table>

**Total Construction Items** $797,250

- Engineering/Contracts/Bidding @ 10% $80,000
- Permitting $7,500
- Construction Observation @ 8% $64,000
- Quality Control Testing $12,000
- Contingency @ 20% $159,000

**ESTIMATED TOTAL (rounded to nearest $1,000)** $1,120,000

**Notes:**

1. Permitting costs are estimated based on preliminary discussions with the BLM and Corp of Engineers
2. Demolished concrete from headwalls and tunnel invert is assumed be stockpiled within a 1/2 mile haul of the tunnel location
3. Construction observation is based on one full time employee for a 3 month construction schedule
### TABLE 3 - OPEN CUT

**SHELL CANAL TUNNEL**

**ENGINEER’S OPINION OF PROBABLE CONSTRUCTION COSTS**

*September 6, 2011*

<table>
<thead>
<tr>
<th>Construction Item</th>
<th>Quantity</th>
<th>Unit</th>
<th>Cost</th>
<th>Extension</th>
</tr>
</thead>
<tbody>
<tr>
<td>1 Mobilization, Bonding, Insurance @ 10%</td>
<td>1</td>
<td>LS</td>
<td>$74,900</td>
<td>$74,900</td>
</tr>
<tr>
<td>2 Site Access</td>
<td>1</td>
<td>LS</td>
<td>$15,000</td>
<td>$15,000</td>
</tr>
<tr>
<td>3 Earthwork - Cut and Fill (Existing Grade - 10 FT Deep)</td>
<td>50,000</td>
<td>CY</td>
<td>$4</td>
<td>$200,000</td>
</tr>
<tr>
<td>4 Earthwork - Cut and Fill (Below 10 FT Deep)</td>
<td>68,000</td>
<td>CY</td>
<td>$7</td>
<td>$476,000</td>
</tr>
<tr>
<td>5 Demolition - Concrete Tunnel</td>
<td>1</td>
<td>LS</td>
<td>$40,000</td>
<td>$40,000</td>
</tr>
<tr>
<td>6 Road Surfacing</td>
<td>1,200</td>
<td>CY</td>
<td>$15</td>
<td>$18,000</td>
</tr>
<tr>
<td>7 Erosion Control/ Storm Water Management</td>
<td>1</td>
<td>LS</td>
<td>$4,000</td>
<td>$4,000</td>
</tr>
</tbody>
</table>

**Total Construction Items** $827,900

- Engineering/Contracts/Bidding @ 10% $83,000
- Permitting $10,000
- Construction Observation @ 8% $66,000
- Quality Control Testing $6,000
- Contingency @ 20% $166,000

**ESTIMATED TOTAL (rounded to nearest $1,000)** $1,159,000

**Notes:**
1. Excavated soil assumed to be hauled and placed within 1/2 mile from the tunnel location with earth moving scrappers and or off road hual trucks
2. Demolished concrete from tunnel is assumed be stockpiled within a 1/2 mile haul of the tunnel location
3. Permitting costs are estimated based on preliminary discussions with the BLM and Corp of Engineers
4. Construction observation is based on one full time employee for a 3 month construction schedule
TUNNEL SLEEVE CONCEPTUAL DRAWINGS
1. Horizontal Datum: NAD83 / WGS84 / NAD 1983(ED50 / NAD27)
   - Wyoming East Central Zone (WESCZ, UTM, LIMITS)
2. Vertical Datum: NAVD88
3. Field work for tunnel & canal survey conducted in Nov, 2019 by
   Paul Reib, P.E.

NOTES:
1. There are two contour map surrogates used in this plan set.
   The primary survey of the area was conducted in November
   2019 using NAVD88. Survey outside the limits of the primary
   survey is shown for reference only and is from old maps
   using NAVD88.
2. Use recommended SRTM3 data for revised plan.
3. All grading quantities based on tunnel & canal survey.
4. Further survey required to complete grading plan.

Survey Control Points Table

<table>
<thead>
<tr>
<th>Control Point</th>
<th>X (m)</th>
<th>Y (m)</th>
<th>Z (m)</th>
<th>Elev. (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>T0127alous</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12.0</td>
</tr>
<tr>
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<td>12.0</td>
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<td>12.0</td>
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<tr>
<td>T0127alous</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>12.0</td>
</tr>
</tbody>
</table>

ALL SURVEY CONTROL NOTES (MARKED)

SHELL CANAL TUNNEL

Survey Control / Existing Conditions

DIRECTIONS

REVISED

REVISION
<table>
<thead>
<tr>
<th>DATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>2021-01-01</td>
</tr>
</tbody>
</table>
NOTES:

1. CONTRACTOR TO FIELD VERIFY MEASUREMENTS PRIOR TO ORDERING HOPE PIPES.
2. CLEARING & REMOVAL OF OVERGROWTH & VEGETATION TO PROVIDE A CLEAN SURFACE PRIOR TO INSTALLING LINING PIPES.
3. INSTALL LINING PIPES TO HAVE A CONSTANT GRADE (PER PLAN) WITHOUT HILLS AND LOW POINTS.
4. BANDING & DOWELING SHALL BE USED TO PREVENT MOVEMENT OF THE PIPES DURING PLACEMENT OF THE CELLULAR CONCRETE.
5. DAMAGED OR DEFECTIVE HOPE PIPES, INCLUDING HOPE PIPES FROM STA D-0.0 TO D-9.95 TO BE REMOVED AND DISPOSED OF PROPERLY.
6. BACKFILLING SHOULD BE REQUIRED AT EACH END OF HOPE PIPES TO RETAIN CELLULAR CONCRETE STABILIZATION. PLACEMENT SHOULD GENERAL PROCEED FROM INVERT TO CROWN AND FROM DOWNSTREAM TO UPSTREAM.
SURVEY CONTROL NOTES (TUNNEL & CANAL)

1. HORIZONTAL DATUM U.S. GEODETIC PLANE 1983 (WGS84) EQUATORIAL, WYOMING EAST CENTRAL ZONE (USE U.T.P. UNITS)
2. VERTICAL DATUM NAVD88 (COMPUTED USING USGS)
3. PUBLIC WORKS FOR TUNNEL & CANAL SURVEY CONDUCTED IN 2015 BY P. REED-MD

NOTES:
1. THERE ARE TWO CONTOUR MAP SURFACES USED IN THIS PLAN; THE PRIMARY SURVEY OF THE AREA WAS Conducted IN NOVEMBER 2015 USING NAVD88 SURVEY OUTSIDE THE LIMITS OF THE PRIMARY SURVEY. IT IS SHOWN FOR REFERENCE ONLY AND IS FROM LUSC-MAPS USING NAVD88
2. WE RECOMMEND OBTAINING SURVEY DATA TO DEFINE THE CONSTRUCTION LIMIT AND COMPLETE THE TUNNEL PROPOSED GRADES INTO EXISTING GRADES.
3. ALL GRAADING QUANTITIES BASED ON TUNNEL & CANAL SURVEY,
4. FURTHER SURVEY REQUIRED TO COMPLETE GRADES PLANY WASTE AREA FOR EXCAVATED MATERIALS.
NOTES:
1. ALL CROSS SECTIONS ARE CUT LOOKING NW IN MAX.
2. TYPICAL SECTION DIMENSIONS SEE SHEET 15.